A NEW APPROACH FOR OPTICAL MILLIMETER WAVE GENERATION UTILIZING LOCKING TECHNIQUES

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ABSTRACT

A new approach is presented for the optical generation of millimeter waves. Instead of the millimeter wave signal, one of its subharmonics is optically transmitted and the millimeter wave signal is generated utilizing the subharmonic signal as a reference. This way the optical components become much simpler and cheaper. In this procedure a crucial point is the frequency division at millimeter waves. For this purpose a new method is introduced: the superharmonic injection locking of oscillators. The main advantage of the new approach is that it is well applicable even for frequencies at shorter millimeter waves.

INTRODUCTION

The optical generation of millimeter waves is relevant for many practical applications, like mobile communications, antenna remoting, indoor communications, beam forming of phased array antennas, etc. [1-4]. In these areas there is an increasing demand for the application of higher and higher carrier frequencies. This requirement can be met by utilizing optical methods for this purpose. In this paper two approaches are presented for the optical generation of millimeter waves utilizing some new principles and procedures.

One of the presently used methods applies special external modulators to transmit the millimeter wave signal and very high speed photo-detectors to receive it and this way to generate the millimeter wave signal [5-7]. Both the external modulators and the photo-diodes are very expensive at these high frequencies. A further problem is the distortion caused by the fiber in the millimeter wave region mainly when long distances are concerned.

There is another known method which avoids the above last problem. According to this method two lasers are used with off-set frequency stabilization. Their frequency difference is in the millimeter wave (MMW) range. The two beams are transmitted via the fiber and detected by a high speed photodiode. This approach can be used for long distances as well [8-11]. However, the generation of the off-set stabilized laser beams is even more complicated and more costly than the application of a MMW external modulator. The reception side is equally expensive.

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THE NEW APPROACH

The proposed new approach overcomes the before mentioned problems. In the new approach instead of transmitting the millimeter wave signal, a subharmonic of it is optically transmitted and at the reception side the millimeter wave signal is generated utilizing the subharmonic signal as a reference. This way the optical components become less demanding, i.e. much simpler and cheaper optical modulator and photo-detector can be used along with less transmission difficulties in the fiber. At the same time, the electrical part is also relatively simple taking advantage of the application of MMICs. The reference frequency is dependent on the actual application. Usually an optimum is obtained for a specific case.

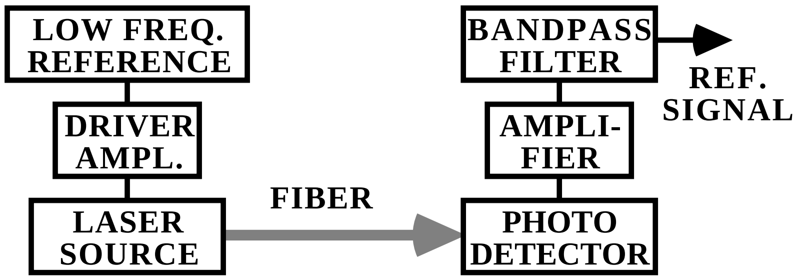

Fig. 1 General block diagram for the optical transmission of the reference signal

The general block diagram for the optical transmission of the reference signal is presented in Fig. 1. At the transmitter side the low frequency reference signal modulates a laser source in intensity. The optical beam carrying the reference signal is transmitted via the fiber. At the receiver side the reference signal is regained by photo-detection. After amplification and filtering this reference signal is used to generate the stable MMW signal.

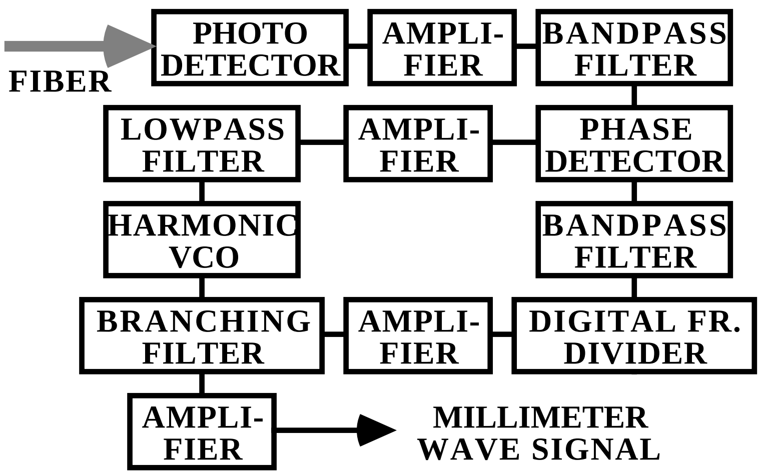

Fig. 2 Millimeter wave generation utilizing a harmonic VCO

The main advantage of this approach is its simplicity and low cost. As the reference frequency is low both the optical transmitter and receiver are significantly less expensive than those applied in the presently used methods. Although the microwave part becomes somewhat more complex its cost will not be high if MMICs are utilized. For the generation of the MMW signal several arrangements can be used. Here two methods are proposed which are the best ones.

In the first new approach - shown in Fig. 2 - a harmonic voltage controlled oscillator (VCO) is used. Its fundamental oscillation frequency is divided by a digital frequency divider. After frequency division this signal is compared to the reference signal in the phase detector. The so called error signal of the phase detector is amplified, filtered and then used to control the harmonic VCO frequency. Thus the VCO frequency is stabilized to the reference signal.

At the same time one of the harmonic frequencies is coupled out of the oscillator and utilized after proper amplification. In our experiment the frequency of the reference signal is 1.1 GHz, the division number of the digital frequency divider is 8, this way the oscillator fundamental frequency is 8.8 GHz. The third harmonic is coupled out from the oscillator what is at 26.4 GHz. In this approach the frequency of the reference signal is thus 24 times lower than the utilized output frequency.

There is a limitation on the generated MMW frequency applying the above method. Namely the upper frequency of the digital frequency dividers is presently around 15 GHz. Thus the highest generated frequency is around 45 GHz if the third harmonic of the oscillation frequency is utilized. Higher order harmonics are at significantly lower power levels and thus their application is not practical.

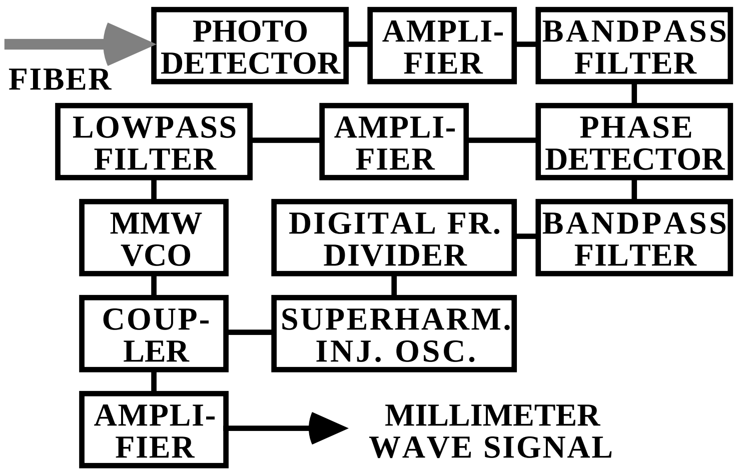

Fig. 3 Millimeter wave generation using a super-harmonic injection locked oscillator

The second new approach overcomes the previous limitations. The block diagram of this approach is shown in Fig. 3. Here the VCO operates in the MMW region. A part of its signal is injected into a lower frequency oscillator which is locked by this signal at one of the superharmonics of the latter oscillator. This way the superharmonic injection locking process is used as an analog frequency division methods. This technique extends the frequency band in which the new method can be used. By the combination of the two methods stable signals can be generated up to about 100 GHz using an optically transmitted low frequency reference signal.

SUPERHARMONIC INJECTION LOCKING

The crucial point in this approach is the frequency division at millimeter wave frequencies. Digital frequency dividers usually don't work at these frequencies as it was mentioned previously. Varactor type dividers need a high power drive what is a significant disadvantage. Therefore, a new method is applied for that task: superharmonic injection locking of oscillators which can conveniently be used as frequency dividers even at short millimeter waves.

Theoretical results

Superharmonic injection locking is possible because of the nonlinear behavior of the microwave oscillators. Due to the nonlinearities in the active device of the oscillator there is a conversion mechanism between the harmonic frequencies of the oscillator which makes possible the locking process utilizing one of the superharmonics.

The nonlinearity of the active device can be described by a nonlinear negative conductance for the theoretical investigations [12]. In this case the I_d current flowing through the active element is dependent on the V_d voltage across this element:

$$I_d = - G_{d0} V_d + G_{d1} V_d^2 + G_{d2} V_d^3 + \dots$$

where G_{d0}, G_{d1}, G_{d2} are the coefficients of the nonlinear negative conductance.

The oscillator operation is dependent on the passive elements of the circuit as well. If only two frequencies are assumed - the fundamental and the second harmonics - the nonlinear equations describing the oscillator operation are:

$$G_{d0} \mathbf{V}_1 - 2 G_{d1} \mathbf{V}_1^* \mathbf{V}_2 - 3 G_{d2} [|\mathbf{V}_1|^2 + + 2 |\mathbf{V}_2|^2] \mathbf{V}_1 = \mathbf{Y}_1 \mathbf{V}_1$$

$$G_{d0} \mathbf{V}_2 - G_{d1} \mathbf{V}_1^2 - 3 G_{d2} [2 |\mathbf{V}_1|^2 + + |\mathbf{V}_2|^2] \mathbf{V}_2 = \mathbf{Y}_2 \mathbf{V}_2 - \mathbf{I}_{g2}$$

Here the bold letters mean complex quantities, the index 1 refers to the fundamental frequency and the index 2 refers to the second harmonic frequency, **V** is the voltage component across the device, **Y** is the resultant admittance of the passive circuit elements, and $\mathbf{I}_{g2}$ is the injected current at the second harmonic frequency.

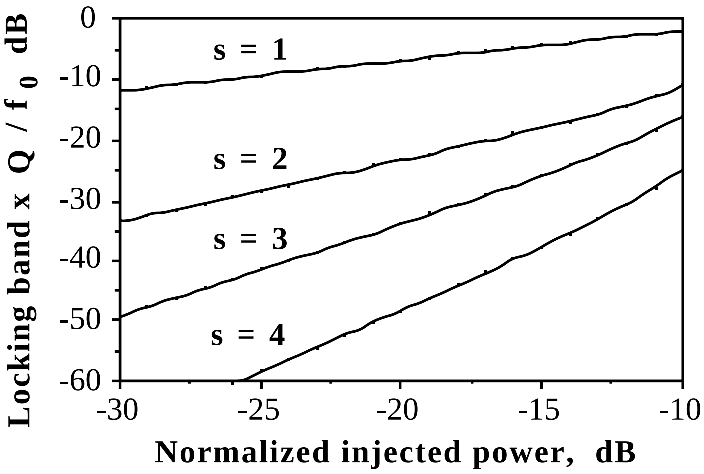

Fig. 4 The calculated locking band times Q/f_0 as a function of the normalized injected power, the parameter of the curves is the division number

The superharmonic injection locking process has been investigated both theoretically and experimentally. The operation of these frequency dividers is determined by the locking band because outside the locking band their operation is unstable. Therefore the locking band was calculated and measured for several division numbers. The calculated values of the locking band are presented in Fig. 4. The locking band is plotted as a function of the normalized injected power multiplied by Q/f_0 as a function of the injected power. Here Q is the quality factor and f_0 is the self oscillation frequency. The parameter of the curves is the superharmonic number, s. As seen the locking band is increased with increasing injected power. However, the locking band is reduced with increasing division number.

Experimental investigations

For the experimental investigations a microstrip oscillator was used which was operated by a microwave transistor as the active element. The spectrum of the generated signals is depicted in Fig. 5 up to the 6th harmonic. Beside the fundamental frequency the second and third harmonics are at a comparable level. The further harmonics are much smaller. That is better seen in Table 1.

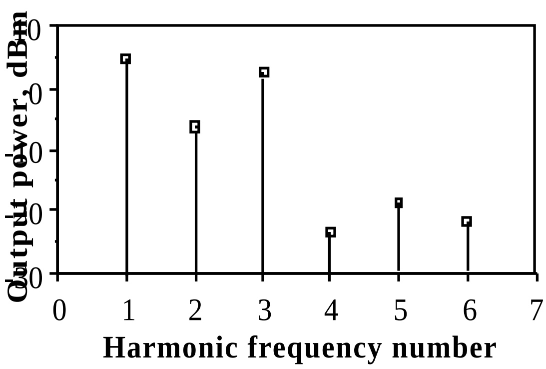

Fig. 5 Output power spectrum of the experimental oscillator

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Table 1

Harmonic number	1	2	3	4	5	6
Output power, dBm	4.6	-6.2	2.4	-23.3	-18.6	-21.6

The locking band was measured also up to the 6th harmonic. The measurement set-up consisted of a microwave oscillator which was injection locked by an external signal via a directional coupler. The fundamental frequency oscillation was indicated by a spectrum analyzer. The frequency of the injected signal was varied. When there was only a single spectral line at the fundamental frequency the locking process was effective. This way the edges of the locking band were experimentally determined.

Figs. 6 and 7 show the experimental results. The injected signal power is given in dBm. Usually the injected power is normalized to the output power of the fundamental frequency. As this power is at 4.6 dBm the normalized injected power is 4.6 dB less than that power in dBm.

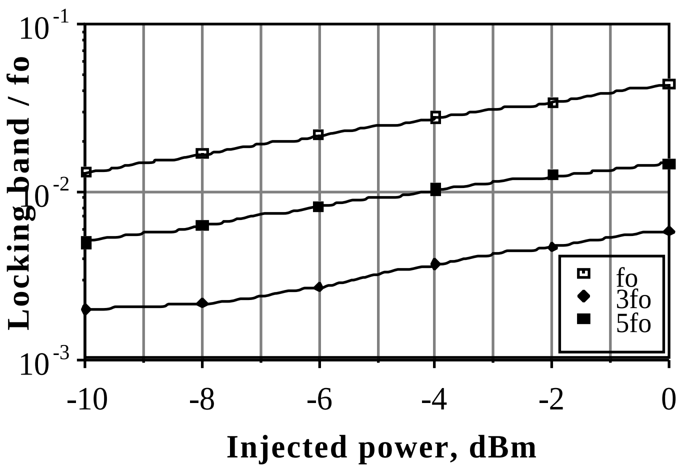

Fig. 6 The measured locking band divided by f_0 as a function of the injected power for odd division numbers

In Fig 6 the locking bands of the odd harmonics are plotted as functions of the injected signal power. It is very interesting to note that a wider locking band is obtained for the 5th harmonic than for the 3rd harmonic. As seen in Fig. 5 the power of the 5th harmonic is much less than that of the 3rd one. Is spite of this the locking process is more efficient for the 5th harmonic than for the 3rd one.

For the even harmonics the experimental results are presented in Fig. 7. Here the curve of the fundamental signal is also shown for comparison. There is not a significant difference between the locking bands of the second and fourth harmonic.

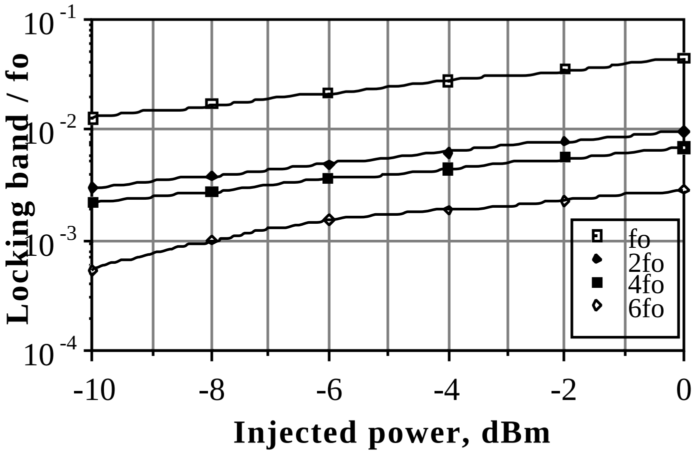

Fig. 7 The measured locking band divided by f_0 as a function of the injected power for even division numbers

CONCLUSIONS

A new approach was presented for the optical generation of millimeter waves. Instead of the millimeter wave signal, one of its subharmonics was optically transmitted and the millimeter wave signal was generated utilizing the subharmonic signal as a reference. A crucial point was the frequency division at millimeter waves. For this a new method was introduced: the superharmonic injection locking of oscillators. The new approach is well applicable even for frequencies in the shorter millimeter wave range.

ACKNOWLEDGMENT

The author acknowledges the Commission of the European Union and the Hungarian National Scientific Research Foundation (OTKA) for their continuous support to his research work. He is also thankful to Mr. A. Hilt for supplying the microwave oscillator for the experiments and to A. Zólomy for performing the measurements.

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